Name: ____________________________________________
Print Neatly. You will lose 1 point if I cannot read your name or perm number.

Perm Number:_____________________________________

All work must be shown on the exam for partial credit. Points will be taken off for incorrect or no units. Calculators are allowed. Cell phones may not be used for calculators. On fundamental and short answer problems you must show your work in order to receive credit for the problem. If your cell phone goes off during the exam you will have your exam removed from you.

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Fundamental Questions

Each of these fundamental chemistry questions is worth 6 points. You must show work to get credit. Little to no partial credit will be rewarded. Make sure to include the correct units on your answers.

1) 6 pts  A chemist fills a reaction vessel with 9.34 atm methane (CH₄) gas, 1.58 atm oxygen (O₂) gas, 4.28 atm carbon dioxide (CO₂) gas, and 7.43 atm hydrogen (H₂) gas at a temperature of 25.0°C.
Under these conditions, calculate the reaction free energy ΔG for the following chemical reaction:

\[ \text{CH}_4(g) + \text{O}_2(g) \rightleftharpoons \text{CO}_2(g) + 2\text{H}_2(g) \]

Round your answer to the nearest kilojoule.

\[
\Delta G = \Delta G^\circ + RT \ln (Q) = \Delta G^\circ + RT \ln \left( \frac{P_{\text{CO}_2} P_{\text{H}_2}^2}{P_{\text{CH}_4} P_{\text{O}_2}^2} \right)
\]

\[
\Delta G^\circ_{rxn} = \Delta G^\circ_{(CO_2)} + 2\Delta G^\circ_{(H_2)} - \Delta G^\circ_{(CH_4)} - \Delta G^\circ_{(O_2)}
\]

\[
\Delta G = -343 \frac{kJ}{mol} + 2 \left( \frac{0 \frac{kJ}{mol}}{0 \frac{mol}{mol}} \right) - (-51 \frac{kJ}{mol}) - (0 \frac{kJ}{mol}) = -336 \frac{kJ}{mol}
\]

2) 6 pts  Given the following data:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔH (kJ)</th>
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<tr>
<td>P₄(s) + 6Cl₂(g) → 4PCl₃(g)</td>
<td>1225.6</td>
</tr>
<tr>
<td>P₄(s) + 5O₂(g) → P₄O₁₀(s)</td>
<td>-2967.3</td>
</tr>
<tr>
<td>PCl₃(g) + Cl₂(g) → PCl₅(g)</td>
<td>-84.2</td>
</tr>
<tr>
<td>PCl₃(g) + ½O₂(g) → Cl₃PO(g)</td>
<td>-285.7</td>
</tr>
</tbody>
</table>

Calculate ΔH for the reaction

P₄O₁₀(s) + 6PCl₅(g) → 10Cl₃PO(g)

\[
\begin{align*}
\text{P}_4(s) + 6\text{Cl}_2(g) &\rightarrow 4\text{PCl}_3(g) \quad \Delta H = 1225.6 \text{kJ} \\
\text{P}_4(s) + 5\text{O}_2(g) &\rightarrow \text{P}_4\text{O}_{10}(s) \quad \Delta H = -2967.3 \text{kJ} \\
\text{PCl}_3(g) + \text{Cl}_2(g) &\rightarrow \text{PCl}_5(g) \quad \Delta H = -84.2 \text{kJ} \\
\text{PCl}_3(g) + \frac{1}{2}\text{O}_2(g) &\rightarrow \text{Cl}_3\text{PO}(g) \quad \Delta H = -285.7 \text{kJ}
\end{align*}
\]

\[
\begin{align*}
\text{P}_4\text{O}_{10}(s) + 6\text{PCl}_5(g) &\rightarrow 10\text{Cl}_3\text{PO}(g) \\
\text{P}_4(s) + 6\text{Cl}_2(g) &\rightarrow 4\text{PCl}_3(g) \quad \Delta H_1 = 1225.6 \text{kJ} \\
\text{P}_4\text{O}_{10}(s) &\rightarrow \text{P}_4(s) + 5\text{O}_2(g) \quad \Delta H_2 = -2967.3 \text{kJ} \\
6(\text{PCl}_3(g) &\rightarrow \text{PCl}_5(g) + \frac{1}{2}\text{Cl}_2(g)) \quad \Delta H_3 = -6\Delta H_1 = -6(-84.2 \text{kJ}) = 505.2 \text{kJ} \\
10(\text{PCl}_3(g) &+ \frac{1}{2}\text{O}_2(g) \rightarrow \text{Cl}_3\text{PO}(g) \quad \Delta H_4 = 10\Delta H_1 = 10(-285.7 \text{kJ}) = -2857 \text{kJ} \\
\Delta H_1 + 6\Delta H_2 + (\Delta H_3 - \Delta H_4) &\rightarrow \Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3 - \Delta H_4
\end{align*}
\]

\[
\begin{align*}
\Delta H &= 1225.6 \text{kJ} + 2967.3 \text{kJ} + 505.2 \text{kJ} - 2857 \text{kJ} = 610.1 \text{kJ}
\end{align*}
\]

3a) 3 pts. For the reaction: 2O(g) → O₂(g)
Predict the signs of ΔH and ΔS.

\[
\Delta H = -(\text{heat must go on side with O}_2 \text{ because heat is needed to break bonds})
\]

\[
\Delta S = -(\text{positional probably decreases when going from 2 to 1})
\]

3b) 3 pts. Would the reaction be more spontaneous at high or low temperatures?

\[
\Delta G = \Delta H - T\Delta S \text{ therefore, the reaction is spontaneous at low temp}
\]
4) Calculate ΔG˚ at 125˚C for the following reaction. Assume that ΔH˚ and ΔS˚ are temperature independent.

2CH₃OH(g) + 3O₂(g) → 2CO₂(g) + 4H₂O(l)

\[ \Delta G_{\text{rxn}} = \Delta H_{\text{rxn}} - T \Delta S_{\text{rxn}} \]

\[ \Delta H_{\text{rxn}}^\circ = 2\Delta H_f^\circ (\text{CO}_2) + 4\Delta H_f^\circ (\text{H}_2\text{O}) - 2\Delta H_f^\circ (\text{CH}_3\text{OH}) - 3\Delta H_f^\circ (\text{O}_2) \]

\[ \Delta S_{\text{rxn}}^\circ = 2S_\text{CO}_2^\circ + 4S_\text{H}_2\text{O}^\circ - 2S_{\text{CH}_3\text{OH}}^\circ - 3S_\text{O}_2^\circ \]

\[ \Delta G_{\text{rxn}}^\circ = \Delta H_{\text{rxn}}^\circ - T \Delta S_{\text{rxn}}^\circ \]

5) A jelly donut (55 g) is burning in a bomb calorimeter resulting in a temperature rise of 25.0˚C. The heat capacity of the calorimeter is 41.7 kJ/˚C. How many calories are in the jelly donut?

\[ \Delta E_{\text{com}} = -q_{\text{cal}} = -C_{\text{cal}}\Delta T = -\left( 41.7 \frac{\text{kJ}}{\text{C}} \right) (25.0^\circ\text{C}) \]

or -249 Cal (kcal)

6) What is K at 25˚C for the reaction 2SO₂(g) + O₂(g) ⇌ 2SO₃(g).

\[ \Delta G^\circ = -RT \ln(K) \]

Determine ΔG˚rxn

\[ \Delta G_{\text{rxn}}^\circ = \sum \Delta G_f^\circ (\text{prod}) - \sum \Delta G_f^\circ (\text{react}) \]

\[ \Delta G_{\text{rxn}}^\circ = 2\Delta G_f^\circ (\text{SO}_3(g)) - 2\Delta G_f^\circ (\text{SO}_2(g)) - \Delta G_f^\circ (\text{O}_2(g)) \]

\[ \Delta G_{\text{rxn}}^\circ = 2 \left( -371 \frac{\text{kJ}}{\text{mol}} \right) - 2 \left( -300 \frac{\text{kJ}}{\text{mol}} \right) - 0 \frac{\text{kJ}}{\text{mol}} = -142 \frac{\text{kJ}}{\text{mol}} \]

\[ K = e^{-\Delta G_{\text{rxn}}^\circ / RT} = e^{142 \frac{\text{kJ}}{\text{mol}} / \left( 0.0083145 \frac{\text{kJ}}{\text{mol} \cdot \text{K}} \right) (298 \text{K})} = 7.76 \times 10^{24} \]
Short Answer Questions

Each of the following short answer questions are worth the noted points. Partial credit will be given. You must show your work to get credit. Make sure to include proper units on your answer.

1a) 12 pts  You are camping and want to make yourself a cup of coffee in the morning with your butane (C\textsubscript{4}H\textsubscript{10}) stove. Before you go to bed you set out 250 mL of water to use for your coffee. When you get up in the morning your water has frozen, you use a thermometer and find the temperature of the ice to be 0˚C. How much butane, in grams, will you use to heat your water to your ideal coffee temperature of 75˚C. Assume no heat from the combustion reaction is lost to the surroundings and that H\textsubscript{2}O(g) forms in the reaction. The ΔH\textsubscript{fus(water)}, ΔH\textsubscript{vap(water)}, ΔH\textsubscript{f(C4H10)} are 6.01 \frac{kJ}{mol}, 40.65 \frac{kJ}{mol}, and -126 \frac{kJ}{mol} respectively. The density of water is 1.00 \frac{g}{ml}.

Reaction of Interest

\[2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(g)\]

Determine ΔH\textsuperscript{o}\textsubscript{rxn}

\[\Delta H_{rxn} = 8\Delta H_f^o(CO_2) + 10\Delta H_f^o(H_2O) - 2\Delta H_f^o(C_4H_{10}) - 13\Delta H_f^o(O_2)\]

\[\Delta H_{rxn} = 8(-393.5 \frac{kJ}{mol}) + 10(-242 \frac{kJ}{mol}) - 2(-126 \frac{kJ}{mol}) - 13(0 \frac{kJ}{mol}) = -5316 \frac{kJ}{mol}\]

Reaction takes place at constant pressure therefore ΔH\textsubscript{rxn} = q\textsubscript{rxn}

All the heat from the reaction goes into the ice/water

\[q_{rxn} = -q_{ice/water} = -(q_{melting} + q_{water})\]

\[q_{melting} = n_{H_2O}\Delta H_{fus}\]

\[n_{H_2O} = 250 \text{ mL} \left(\frac{1.00 \text{ g}}{1 \text{ mL}}\right) \left(\frac{1 \text{ mol}}{18.0148 \text{ g}}\right) = 13.9 \text{ mol}\]

\[q_{melting} = (13.9 \text{ mol}) \left(6.01 \frac{kJ}{mol}\right) = 83.5 \text{ kJ}\]

\[q_{water} = m_{H_2O}C_{H_2O}\Delta T = (250 \text{ g}) \left(4.184 \frac{J}{g^\circ C}\right) \left(75^\circ C - 0^\circ C\right) = 78500 \text{ J} = 78.5 \text{ kJ}\]

\[q_{ice/water} = 83.5 \text{ kJ} + 78.5 \text{ kJ} = 162.0 \text{ kJ} = -q_{rxn}\]

\[-162.0 \text{ kJ} \left(\frac{58.123 \text{ g}}{1 \text{ mol C}_4\text{H}_{10}}\right) \left(\frac{5316 \text{ kJ}}{1 \text{ mol C}_4\text{H}_{10}}\right) = 3.542 \text{ g}\]

1b) 8 pts  What is ΔE, ΔH, and ΔS for the ice/water that was heated.

The ice and the water do not change size therefore no work is done and

\[\Delta E = q = 162.0 \text{ kJ}\]

The process takes place at constant pressure

\[\Delta H = q = 162.0 \text{ kJ}\]

To calculate ΔS break into 2 parts ΔS\textsubscript{melting} and ΔS\textsubscript{water}

\[\Delta S_{melting} = \frac{\Delta H_{melting}}{T} = \frac{83.5 \text{ kJ}}{293 \text{ K}} = 0.306 \frac{kJ}{K}\]

\[\Delta S_{water} = m_{H_2O}C_{H_2O}\ln\left(\frac{T_2}{T_1}\right) = (250 \text{ g}) \left(4.184 \frac{J}{g^\circ C}\right) \ln\left(\frac{348\text{ K}}{273\text{ K}}\right) = 254 \frac{J}{K}\]

\[\Delta S_{tot} = 306 \frac{kJ}{K} + 254 \frac{J}{K} = 560 \frac{J}{K}\]
2) 14 pts 350. mL of 7.0 M H$_2$CO$_3$ and 300. mL of 15.0 M NaOH are mixed in a constant pressure calorimeter with heat capacity of 54 $\frac{J}{^{\circ}C}$. The initial temperature of both solutions are 25.00$^{\circ}$C and the final temperature of the system is 24.84$^{\circ}$C. What is $\Delta H_{rxn}$ in $kJ/mol$. Assume that the heat capacity of the solution is 4.184 $\frac{J}{g \cdot ^{\circ}C}$ and the density of the solution is 1.00 $\frac{g}{ml}$.

Reaction of Interest

H$_2$CO$_3$(aq) + 2NaOH(aq) $\rightarrow$ Na$_2$CO$_3$(aq) + 2H$_2$O(l)

$\Delta H_{rxn} = q_{rxn} = -(q_{sol} + q_{cal})$

$q_{sol} = m_{sol}C_{sol}\Delta T = (650. g) \left(4.184 \frac{J}{g \cdot ^{\circ}C}\right)(24.84^{\circ}C - 25.00^{\circ}C)$

$= -435 J$

$q_{cal} = C_{cal}\Delta T = \left(54 \frac{J}{^{\circ}C}\right)(24.84^{\circ}C - 25.00^{\circ}C) = -8.6 J$

$\Delta H_{rxn} = -(−435 J + -8.6 J) = 443 J$

Change to $kJ/mol$
This is a limiting reagent problem

<table>
<thead>
<tr>
<th></th>
<th>H$_2$CO$_3$</th>
<th>NaOH (L.R.)</th>
<th>Na$_2$CO$_3$</th>
<th>H$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>I(mol)</td>
<td>0.350L(7.0M)</td>
<td>0.300L(15.0M)</td>
<td>0 mol</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>= 2.45 mol</td>
<td>= 4.50 mol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F(mol)</td>
<td>2.45-2.25=0.20 mol</td>
<td>0 mol</td>
<td>2.25 mol</td>
<td>N/A</td>
</tr>
</tbody>
</table>

$\Delta H_{rxn} = \frac{443 J}{4.50 mol} = 98.4 \frac{J}{mol}$

This is for NaOH which has coefficient of 2 in front of it, need to convert to something with a coefficient of 1 in front (ex: H$_2$CO$_3$) therefore multiply by 2.

$\Delta H_{rxn} = 197. \frac{J}{mol} = 0.197 \frac{kJ}{mol}$
Multiple Choice Questions

On the ParScore form you need to fill in your answers, perm number, test version, and name. Failure to do any of these things will result in the **loss of 1 point.** Your perm number is placed and bubbled in under the “ID number.” Do not skip boxes or put in a hyphen; unused boxes should be left blank. Bubble in your test version (A) under the “test form.” Note: Your ParScore forms will not be returned to you, therefore, for your records, you may want to mark your answers on this sheet. Each multiple choice question is worth 5 points.

1. Calculate the $\Delta S$ associated with a process in which 5.00 mol of gas expands reversibly at constant temperature $T=25^\circ C$ from a pressure of 10.0 atm to 1.00 atm.
   
   A) $95.7 \frac{J}{K}$
   
   B) $-95.7 \frac{J}{K}$
   
   C) $-28,500 \frac{J}{K}$
   
   D) $28,500 \frac{J}{K}$
   
   E) None of the above

2. In a system composed of nitrogen gas in a cylinder fitted with a piston, when 2.00 kJ of energy is transferred into the system as heat at an external pressure of 2.00 atm, the nitrogen gas expands from 2.00 L to 5.00 L against the constant pressure. What is $\Delta E$ for the process?
   
   A) $2.61 \text{ kJ}$
   
   B) $1.39 \text{ kJ}$
   
   C) $0 \text{ kJ}$
   
   D) $-0.608 \text{ kJ}$
   
   E) None of the above

3. Two metals of equal mass with different heat capacities are subjected to the same amount of heat. Which undergoes the smaller change in temperature?
   
   A) To determine this, you need to know which metals you are talking about.
   
   B) The metal with the lower heat capacity.
   
   C) To determine this, you need to know the initial temperatures of the metals.
   
   D) **The metal with the higher heat capacity.**
   
   E) Both undergo the same change in temperature.
4. Which of the following statements is(are) true?
   A) The heat of reaction and change in enthalpy can always be used interchangeably.
   B) Enthalpy is a state function.
   C) A chemist takes the point of view of the surroundings when determining the sign for work or heat.
   D) In exothermic reactions, the reactants are lower in potential energy than the products.
   E) At least two of these statements are true.

Consider a process carried out on 1.00 mol of a monatomic ideal gas by the following two different pathways. The first pathway is A (3.00 atm, 20.0 L) to C (1.00 atm, 20.0 L) to D (1.00 atm, 50.0 L); and the second pathway is A (3.00 atm, 20.0 L) to B (3.00 atm, 50.0 L) to D (1.00 atm, 50.0 L). In each case, the gas is taken from state A to state D.

5. Calculate \( \Delta H_{ABD} \).
   A) \(-475\ \text{L} \cdot \text{atm}\)
   B) \(475\ \text{L} \cdot \text{atm}\)
   C) \(-25\ \text{L} \cdot \text{atm}\)
   D) \(25\ \text{L} \cdot \text{atm}\)
   E) none of these

6. Choose the correct statement.
   A) At constant pressure and temperature, a decrease in free energy ensures an increase in the entropy of the system.
   B) A reaction that exhibits a negative value of \( \Delta S \) cannot be spontaneous.
   C) Free energy is independent of temperature.
   D) Exothermic reactions are always spontaneous.
   E) None of the above